PROCEEDINGS

Watershed Management Research Conference on Collection and Compilation of Streamflow Records

Laconia, New Hampshire
June 12-14, 1962

Northeastern Forest Experiment Station
Forest Service, U. S. Department of Agriculture
Upper Darby, Pa.

PREFACE

The objectives of this conference were two: (1) to review and compare present methods of collecting and compiling streamflow data as practiced by watershed research projects at Parsons, W. Va., New Lisbon, N. J., and West Thornton, N. H., and (2) to learn about recently developed machine methods for recording and compiling data and to compare these with our present methods in respect to efficiency and cost.

These Proceedings consist of several papers prepared for this conference and introductory and summary statements. The considerable discussion of these papers is briefly summarized. In an Appendix are given a summary of Coweeta's experience in this field, and a determination of the error involved in our point-picking procedure. We are indebted to Alden R. Hibbert of the Southeastern Station for the Coweeta write-up, and to Henry Anderson for information on point-picking tests made at the Pacific Southwest Forest Experiment Station.

PROGRAM

Tuesday, June 12

Opening remarks by Lull; report on streamflow records by Reinhart; reports on the present methods of securing, compiling and checking data by Fridley, Hornbeck, Reigner, Lavigne, Leonard, and Hart.

Wednesday, June 13

Reports on new methods for measuring streamflow, for compiling streamflow data, and for computation by Pierce, Reigner, Bickford, and Wilson; also reports on research at Coweeta, Penn State, Syracuse, and Toronto by Hibbert, Sopper, Satterlund, Eschner, and Farrar.

Thursday, June 14

Field trip to Hubbard Brook led by Pierce; summary statement on present procedures for recording, compiling, and checking by Reinhart; summary statement on machine possibilities by Reigner; and a final statement on what to do by Lull.

Participants

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CONTENTS

OPENING REMARKS

Howard W. Lull

In the summer of 1954 we were gaging 7 experimental watersheds; this summer we are gaging 27, and within 3 to 4 years we will have well over 30 stations. In collecting and compiling these records we have followed the same general procedures at each of our watershed projects, but each project has also developed certain refinements and short-cuts. These bear description. Also, we have never analyzed how much time it takes to process these records, the need for chart corrections, and the value of checking. We will go over these matters in the next three days.

Another development since 1954 has been the appearance of the machine age in streamflow data collection and compilation. We have had encouraging reports on the speed and facility of chart scanners and digital computers. These have both aroused our curiosity and fostered a feeling that we are falling behind times with our horse and buggy pencil-pushing methods. So, at this meeting we will look into these new methods and consider joining the machines.

But, if we do, we will have to justify it. We can't justify it from the standpoint that we have a barn-full of accumulated records to compile. With your outmoded facilities you have managed to keep up with your records; justification will have to be based on doing a better and more efficient job.

Finally, I remind you--though it isn't really necessary--that collecting and compiling streamflow data is just a small part of your job that covers the research cycle from the germ of an idea through work plan to publication. Stream gaging is engrossing, the weirs give a sense of substance, the accumulated records suggest a job being done, and the systems are great for show-me trips. But stream gaging isn't research, and research is what we get paid for.

WHAT WE WANT FROM STREAMFLOW RECORDS

Kenneth G. Reinhart

We could take the facetious approach: we want an imposing shelf of bound records. And 10 years or so on a number of watersheds can be an impressive array.

Or, if we expect to earn our pay, we need to compile records for analyses that will answer the questions posed in our research program.

TYPES OF USE OF RECORDS

There are perhaps two major ways in which we use our records: (1) streamflow for a given area as related to geology, topography, climate, etc.; (2) analysis to determine results of treatment--"before and after" comparisons.

The use indicated in item 1 has led to some interesting and informative publications--such as the Rocky Mountain Station's Precipitation and streamflow in the Black Hills and our Water yields from small forested watersheds. In this situation we are dealing with total amounts--not differences--and the requirements are not too exacting. To determine results of treatment we do deal with differences rather than total amounts and we generally have to be a lot more fussy.

KINDS OF COMPILATIONS FOR ANALYSIS

First we will list the kinds of compilations we are likely to make:

1. Total discharge: annual, seasonal, monthly, daily.
2. Low flows: number of days in year below a given rate of discharge, and other compilations.
3. High flow or storm flow: instantaneous peaks, quantity of storm discharge, frequencies.
4. Flow duration.
5. Water quality: turbidity, pH, alkalinity, specific conductance, temperature.

Excluding water quality, the basic building block for most analyses is total or mean flow for the calendar day. Once we have this, the compilation of monthly, seasonal, and annual totals is relatively simple. Certain measures of low flow and high flow can also be obtained from the record by days Flow duration curves can be based on this same record and average recession curves can be determined.

We would like to analyze flood flows but we will never have enough floods in a study period--either in calibration or treatment period--to make much of an analysis. We have to be satisfied with analyzing "high flows" or "storm flows" (even though most of them do not reach the flood category) and hope that we can then make inferences as to the effect of the treatment on floods.

Water quality measurements are for many reasons in a separate category. We don't need a streamgaging station in order to make a study involving water quality, but in some situations we will want to relate quality to rate of discharge.

Measuring water quality is a sampling process (we usually get a very small sample); whereas discharge measurement is not. It is well to hold this difference in mind.

In our watershed research, turbidity is the most common characteristic measured. Generally, our treatments cause manyfold increases in turbidity. For this reason, sophisticated analysis may not be required and data collection and compilation are not so exacting.

The other quality characteristics are generally less affected by treatment; changes are not obvious. Regression analysis, on the Fernow at least, has not been appropriate. We have used simple "T"-tests on "before and after" means or paired values.

ROUTINE AND SPECIAL COMPILATIONS

In scheduling office work, we have set up the compilation of discharge by days, months, seasons and years as a routine procedure. (Some other compilations have also been handled this way). In other words, we know we will use this data so we go ahead and compile it; we don't wait until the time we are going to make the analysis.

For some things, such as quantity of storm discharge and comparison of individual storm events, we have had to go back to the basic record, the charts. This can be a time-consuming process. Whenever possible, we should look ahead to the kind of analysis we are going to make and set up the necessary routine compilations beforehand. This is also a sounder approach from the statistical viewpoint. When considering a particular analysis, perhaps we should first ask if it can be accomplished using the basic building block--discharge by calendar days.

STANDARDS OF ACCURACY

To reach our research objectives, we probably need all the accuracy we can get. Of course, there is a limit to the expenditures we can make to get accuracy. But to date, we have not been able to design our experiments and set up standards of accuracy that must be met. Rather, we have been able to achieve a certain degree of accuracy and have had to tailor our experiments to that accuracy.

The accuracy we strive for can depend to a considerable degree on our objectives. If we were interested in determining results on the basis of annual or seasonal discharge only, we could be very sloppy in our measurements of low flows. If this were the case, the permissible change in head before making a time-interval break in the hydrograph would be larger for low flows than for high flows. Actually, I guess all of us do the opposite of this; we are very interested in low flows because forest cutting seems to have a definite effect on them and, from a practical standpoint, the increase in low flows may be the most important.

Your guess is probably as good as mine as to the accuracy we can achieve in streamgaging. We try to read to the nearest 0.001 foot but I doubt that we can say that is a measure of our precision. Then there are errors due to debris, instrument irregularities, and the like. Additional error is involved in working up the charts and arriving at discharge values, for days or other periods.

The precision we use in the compilation process must of course be related to the accuracy of the field records. It is foolish to carry values out to numerous decimal places based on relatively inaccurate field data; however, we work hard to achieve the best accuracy we can in the field and I think we should make sure that we don't squander any of it by short cuts or easier compilation methods. I would rather err on the side of being a little too painstaking in the office.

For several years, we tabulated mean daily c.s.m. to four decimal places. Now we tabulate to three places and I feel sure it is far enough. A good case could be made for using only two decimal places. For instance, in analysis, I generally use streamflow amounts to the nearest 0.01 inch (sometimes only to 0.1 inch; almost never to 0.001 inch). Assuming that the error in rounding from three places to two is in each case 0.005 and cumulative over a month, the error in the month total would be only 0.005 x 30 x 0.03719 = 0.006 area inch. Actually the error involved would, on the average, be much less because to a large extent it is compensating.

THE PREDICTION EQUATION

The best estimate of our overall accuracy comes in the calibration analysis. The precision of the prediction equation, as measured by the correlation coefficient and the error of estimate, is the real proof of the pudding. If this prediction is good, it means that two conditions have been met: (1) The two watersheds in the analysis (in the case of the control-watershed approach) are naturally well correlated and (2) measurements have been satisfactory. If either of these two conditions is not met the prediction equation will not be satisfactory.

We often get very high correlation coefficients: these may not mean very much except for comparison purposes. The fact that the correlation is significant (i.e., both watersheds have high flow in rainy periods and low flow in dry periods) doesn't mean a lot. We know that much without any fancy analysis.

The error of estimate is usually more meaningful. It tells us, in terms of area inches, for example, just how good or poor our prediction equation is. Still, the error of estimate alone does not tell us all we need to know. A very precise prediction equation is needed if we hope to determine the result of a treatment which will have a small effect. A less precise prediction is required for a treatment with a very big effect.

This is the reason for using the relationship of Wilm [1/] and of Kovner and Evans [2/]: $sy.x^2/d^2$. The numerator is the error variance and the denominator is the square of the expected change in the mean value of Y (the flow of the treated watershed). If we can determine this proportion, we are in a position to determine whether or not our prediction equation is adequate.

I have really said very little about the required standards of accuracy in compiling streamflow records: I am not in a position to say very much. My personal feeling is that if any easy or short-cut method gives a result that is more than 1 or 2 percent less accurate than an alternative method, we should hesitate to use it. This is said with the understanding that our discharge measurements are basically probably much less accurate than this.

1/ Wilm, H. G. How long should experimental watersheds be calibrated? Trans. Amer. Geophys. Union 30: 272-278, 1949.

2/ Kovner, J. L., and Evans, T. C. A method for determining the minimum duration of watershed experiments. Trans. Amer. Geophys. Union 35: 608-612, 1954.

STREAMGAGING INSTRUMENTS IN USE ON THE FERNOW EXPERIMENTAL WATERSHEDS

Burley D. Fridley

The present watershed management research program at the Fernow requires operation of nine streamgaging stations. Six of these are equipped with Friez model FW-1 continuous water level recorders and three are equipped with Stevens model A-35 continuous water level recorders. The FW-1 recorders are geared for a 4-day chart, and the charts are changed every 7th day. The A-35 recorders are equipped with a 180-day strip chart; however, the recorders are visited weekly to make any necessary corrections for stage and time.

INSTRUMENTATION DIFFICULTIES

One problem in instrumentation is the occurrence of a lag or step-down effect in the pen trace. This occurs when the pen remains level for an hour or more, though the stage is falling; then, in a step-like motion, the trace falls to the proper level. Another problem is the difficulty in obtaining the correct clock weights on the A-35 recorder.

A previous problem of frost forming on the pulley wheels of the recorders has been solved by ventilating the gage houses. Debris collecting in the notch is still a problem; however, it is possible that this could be reduced by cutting more of the trees in the immediate vicinity of the weir.

Obtaining an accurate hook-gage reading when high flows or wind cause excessive surface movement on the weir pond is also a difficulty. (We use the hook gage in the open weir pond). Without an accurate hook-gage reading, the pen cannot be set to the correct water level. A final problem is mice and groundhogs entering the gage houses and chewing up various items of value. Trapping of mice has been tried but there are too many of them.

INSTRUMENT MAINTENANCE

During the past few years all clock maintenance has been done at the Fernow office rather than sending them to a clock repairman. Cleaning and oiling a clock takes about 2 1/2 hours, a sizable savings over the time the clock would be tied up if it were sent out to be repaired. We try to clean each clock at least once a year; this regular cleaning schedule is largely responsible for the small amount of lost records due to clock failure.

During the 10 years that the Fernow Watersheds have been in operation, the same person has collected records and cared for instruments. This has permitted reading correction of any errors or instrument failures.

MARKING AND TABULATING CHARTS

Prior to the actual marking of the charts for point-picking, errors in the hydrograph line that have been caused by debris or some other cause are corrected. All charts are also checked for errors in time and gage height, and the A-35 charts are checked for chart expansion errors. Necessary corrections, except those for expansion, are prorated over the entire week of record. Marking the charts consists of marking point-picking intervals on the hydrograph and placing a dot at the mean gage height for each interval.

Tabulation of the charts consists of recording, on the chart, the day of the month, time at end of each interval during the day, and mean gage height for each interval. If a storm is involved and the stage of the resulting maximum peak is 0.3 feet or over, the time that storm runoff began and the height of the maximum peak are also recorded on the chart. Both marking and tabulation are checked, preferably by someone other than the person who did the original operation.

COMPILATION OF STREAM DISCHARGE FROM CHART DATA

James W. Hornbeck

Upon completion of marking and tabulating the water level charts, the date, time at the end of each interval, and the average gage height for the interval are transferred to Form NE-56. The mean daily discharge in c.s.m. is computed on Form NE-56 by accumulate multiplying, for each calendar day, the time interval in minutes by a rating factor which corresponds to the average gage height for each interval.

The rating factor is taken from a table of rating factors which has been prepared for each watershed. This table takes care of three operations in one: (1) stage-height to discharge relation, (2) minutes to seconds conversion and (3) c.f.s. to c.s.m. conversion. Tabular values for each stage height are computed as follows: c.f.s. from discharge table x 60 x area factor for watershed.

The computed values for mean daily c.s.m. are next copied from Form NE-56 to Form 7 and the mean c.s.m. and area inches by month, season, and year are computed. Mean values in c.s.m. for any desired period are obtained by appropriate addition and division of the mean daily c.s.m. values. Area inches of streamflow for a desired period are computed by multiplying the total of the mean daily c.s.m. for the period by the factor 0.03719. In addition to c.s.m. and area-inch values, the precipitation that occurred during each month, season, and year is also recorded on Form 7 for use when making precipitation-runoff comparisons.

MARKING, TABULATING, AND COMPUTING

The present arrangement for compiling daily discharge data consists of marking and tabulating the water-level charts in the Fernow office, and then sending the tabulated charts to Elkins where clerks complete the copying and computations necessary on Forms NE-56 and 7.

Since the inception of the watershed management studies on the Fernow, marking the charts has usually been the responsibility of the same person who operates the instruments. This has been an especially desirable practice since this person is best qualified to understand and correct any errors and abnormalities that are shown by the pen trace. The checking of the chart marking, tabulation of the charts, and checking of the tabulations are done by the Fernow watershed staff but they could probably be done by the clerical staff in Elkins without any loss of accuracy and with a savings of time and cost.

Form NE-56

U. S. DEPARTMENT OF AGRICULTURE

Forest Service

RECORD OF RUNOFF

Weir No. ____ Month ____ Year ____

Date	Time	Time interval	Gage height	Discharge factor: For interval	Discharge factor: For max. peaks	C.S.M.: For the day	C.S.M.: For max. peaks	Remarks
	Hr.Min.	Min.	Ft.					

Tabulated by: ________ Date ________ Checked by: ________ Date ________

Computed by: ________ Date ________ Checked by: ________ Date ________

Sheet ____ of ____ Sheets

U. S. Department of Agriculture
Forest Service

Form 7

DRAINAGE DISCHARGE DATA
Mean c.s.m. by Days, Months, and
Growing Season

Experimental area: ____________ Computed by: ____________
Drainage Basin No. ____________ Area: ________ acres Checked by: ____________

Date	May	June	July	August	September	October
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
Total						
Mean						
Area inches						
In. precipitation						
Runoff % of pre.						

	For 6 months ending Oct. 31	For 12 months ending Oct. 31
Total	____________	____________
Mean	____________	____________
Area inches	____________	____________
In. precipitation	____________	____________
Runoff % of pre.	____________	____________

Period: May 1, ____ to October 31, ____

U. S. Department of Agriculture
Forest Service
DRAINAGE DISCHARGE DATA
Mean c.s.m. by Days, Months, and
Dormant Season

Form 7a

Experimental area: ____________ Computed by: ____________
Drainage basin No. ________ Area: ________ acres Checked by: ____________

Date	November	December	January	February	March	April
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
Total						
Mean						
Area inches						
In. precipitation						
Runoff % of pre.						

	For 6 months ending April 30	For 12 months ending April 30
Total	________	________
Mean	________	________
Area inches	________	________
In. precipitation	________	________
Runoff % of pre.	________	________

Period: November 1, ____ to April 30, ____

Computation and checking of Forms NE-56 and 7 by a clerical staff has proved very satisfactory. In most instances these forms can be completed more rapidly and accurately by clerks than by professional personnel.

TIME AND COSTS

The time and costs required to process streamflow data for one watershed for one year are given in Table 1. Time requirements are averages for the various compilation operations performed for all nine of the Fernow Watersheds. The time requirement data for the FW-1 water level chart were collected while working on streamflow charts for July 31, 1961 through November 6, 1961. The A-35 time requirement data were collected while working on streamflow charts for parts of the period between January 25, 1961 and January 3, 1962. The time requirements shown in Table 1 are based on an average of 3 time intervals per day on both the A-35 and FW-1 water level charts.

Table 1.--Time and cost required to process one year of streamflow records from a single watershed when using either the A-35 or FW-1 water level recorder

Operation	Time/year				Cost	
	Original		Check		Original	Check
	Hr.	Min.	Hr.	Min.		
1. Marking charts: A-35	17	20	2	44	$40.48	$6.41
FW-1	10	10	2	34	23.56	5.82
2. Tabulating charts: A-35	4	16	3	54	9.90	9.09
FW-1	4	16	3	54	9.90	9.09
3. Copy to NE-56: A-35	2	52		51	5.48	1.62
FW-1	2	26		47	4.65	1.50
4. Computing minutes per interval	1	9	Self-checking		2.20	0
5. Discharge factor	1	31		51	2.90	1.62
6 Compute NE-56	2	8	1	31	4.07	2.90
7. Transfer to Form 7		26		11	.83	.35
8. Compute Form 7		36		26	1.15	.83
Total/year A-35	30	18	10	28	$67.01*	$22.82*
FW-1	22	42	10	14	49.26*	22.11*

* At least 10 percent of the total cost figures per year should be added to cover handling and filing of the charts and forms.

Cost requirements are based on the charts being marked and tabulated by a GS-5 ($4840) and the remaining compilations being completed by a GS-3 ($3970). In many cases the marking and tabbing of the charts are done by a GS-7 or 9 which would raise costs.

One of the most striking differences in Table 1 is the greater amount of time required to mark the A-35 chart as compared to the FW-1. Much of this difference is probably due to the fact that corrections for expansion were made on the A-35 and not on the FW-1 charts. Other than marking, there is very little difference in the time requirements for the two types of charts.

FILING OF DATA

Completed charts and forms for the Fernow Watersheds are filed in a fireproof vault where they are properly labeled and easily accessible. For convenience, a loose leaf binder containing carbon copies of all completed Form 7's is kept in the office. The most favorable procedure to date for filing A-35 charts consists of running the charts through a simply constructed chart-folder and filing in manila folders.

PRESENT METHODS OF COLLECTING AND COMPILING DATA AT THE NEW LISBON CENTER

Irvin C. Reigner

At present, we are compiling streamflow records for six stations, three operated by the Baltimore (Md) Bureau of Water Supply and three on the Pequannock Watershed of Newark, N. J Both cooperators undertook to compile the data using clerical and other non-professional help but the work bogged down and we took over the job. Another cooperator, The Pennsylvania State University, has been processing its own records from six gaging stations. Uncompiled records are accumulating and relief will soon be needed. At the Dilldown Watershed on the Delaware-Lehigh Experimental Forest in Pennsylvania the U. S. Geological Survey and the Department of Forests and Waters collect and compile the streamflow records as one of the state-wide surface-water station records. (This, I contend, is the best way to handle streamflow records: let some other reliable agency do it.)

At the Baltimore and Newark Watersheds, FW-1 recorders are in operation. They present no difficulties except when observers are inaccurate or forgetful. The records generally have been acceptable. Penn State has both FW-1 and FW-2 recorders in operation.

Compilation of streamflow charts at the New Lisbon Center is being carried on by a forestry aide hired last October. As there was nearly a 3-year backlog from six stations, this has been his major task. He has just about brought these stations up to date, and will have no difficulty keeping them current.

He follows, generally, the Fernow methods.[3/] At first, I had him break the day into 6-hour intervals and compute the average discharge for the interval. When he understood this system well, I introduced the faster point-picking method in which only one point per day was read in those days with minimum variation. He now uses the latter method whenever possible. He applies time and head corrections as outlined by Reinhart. So far, no checks have been applied to his compilations, but a summer assistant will be given the job of making sample checks

We recently made time studies on 3 station years from Baltimore watersheds. Here are the average times for the various operations, based on an average of 865 points per year.

3/ Instructions for compiling climate and runoff data. K. G. Reinhart, Elkins Research Center, March 1959

	Hours
Dating, marking charts, entering date and time on form, computing time interval, reading and entering gage height..........................	11.5
Entering discharge rate for gage height.............	2.0
Computing average discharge for interval............	3.5
Computing runoff in c.f.s. for interval, monthly total in c.f s. and area-inches, and annual total in inches..................................	9.5
Total..	26.5

The Baltimore watersheds have a very constant discharge rate, as shown in the low number of points per station year. The 3 station years ranged between 851 and 884 points. The Newark watersheds have greater fluctuations, in the one station-year counted there were 1,567 points.

STREAMFLOW COMPILATION PROCEDURES AND A TIME REQUIRED FOR PROCESSING DATA FROM AN A-35 WATER-STAGE RECORDER

Raymond W. Lavigne

This report describes the procedure and time required to compile the runoff at a stream-gaging station equipped with a Stevens A-35 water-stage recorder at the Hubbard Brook Experimental Forest.

The following outline presents the procedure used in compiling streamflow data from the time the chart is removed till the data are tabulated and summarized. A detailed account of the procedure is not presented herein but is given in the Hubbard Brook instruction manual. [4/]

Streamflow charts from the A-35 are removed every 2 weeks. Stage height and time are checked and noted; unless there is a malfunction or gross error (15 minutes in time or .004 in stage height) no adjustment is made on the instrument.

The nine separate operations involved in compiling the data are as follows:

1. Setup

   Check chart for errors. Add dates. Mark midnight lines. Mark beginning and ending of precipitation and daily temperature when needed.

2. Corrections

   Mark daily corrections in time and gage height. Make expansion adjustment graph. Adjust discharge curve to compensate for irregularities caused by ice, debris or lost record and describe the corrections.

3. Marking

   Mark runoff rises /R for rainfall rises, R (s) for snow melt rises, and R (sr) for rises produced by both rainfall and melting snow) and peaks MP for rainfall peaks, MP (s) for snow melt peaks, and MP (sr) for both rain and snow/. Mark time of breaks in hydrograph. Determine and mark mean gage heights between breaks. Make corrections in time and gage height.

4/ Instruction manual for compiling climatic and streamflow data on the Hubbard Brook Experimental Forest. Richard S. Sartz, 1958.

4. Tabulating

Transfer data, time of breaks, gage heights, storm rises, and maximum peaks to Form 56a.

5. Computing time

Convert time between breaks in the hydrograph to minutes.

6. Tabulating discharge factors

Convert gage heights to discharge rating table factors.

7. Computing Form 56a

Convert mean gage heights and maximum peaks to daily c.s.m.

8. Tabulating Form L68

Transfer daily c.s.m. to summary form.

9. Computing Form L68

Compute runoff as a percent of precipitation by month and year.

A time study was made of all the above operations. The times required for each of the items listed below apply strictly for that operation and do not include interruptions of any kind.

Form L- 56A
3/58

U. S. Department of Agriculture
Forest Service

RUNOFF RECORD, WATERSHED # ___

Hubbard Brook Experimental Forest

Month & Year ____________

Date	Time	Discharge Intervals				Maximum Peaks			Notes
		Gage Ht.	Time (min.)	Discharge Factor	Daily C.S.M.	Gage Ht.	Discharge Factor	C.S.M. (8x1.44)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)

Tabulated by ____________ Computed by ____________ Checked by ____________

______ of ______

L-68
H.B.E.F.
2/61

Northeastern Forest Experiment Station

Year ________

DRAINAGE DISCHARGE DATA

Mean c.s.m. by days, months, and year

Watershed No. ________ Area: ________ acres

Computed by: ________
Checked by: ________

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
Total												
Mean												
Area In.												
In. Precip												
R.O. % of precip.												

	For year
Total	________
Mean	________
Area Inches	________
In. Precipitation	________
Runoff % of precip.	________

Table 2.--Time study for streamflow compilation of one year's record from one watershed

Operation	Minimum	Maximum		Average/ 2 week-chart A-35		Total for year		Subtotal	
	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
A. Hydrographs									
1. Setup	5	--	20	--	11	4	35	--	--
2. Corrections	0	--	25	--	8	3	30	--	--
3. Marking	10	3	25	1	19	27	5	35	30
B. Tabulation and computation									
4. Tabulating	--	--	--	--	12	5	35	--	--
5. Computing time	--	--	--	--	4	2	00	--	--
6. Tabulating discharge factors	--	--	--	--	9	4	10	--	--
7. Computing Form 56a	--	--	--	--	8	3	25	--	--
8. Tabulating Form L68	--	--	--	--	2	--	45	--	--
9. Computing Form L68	--	--	--	--	1	--	35	16	30
Total	--	--	--	--	--	--	--	52	00

STAGE HEIGHT: HOW CLOSE DO YOU READ IT?

Raymond E. Leonard

The standard chart used on the Stevens A-35 streamflow recorders is imprinted with stage height divisions of 0.10 and 0.01 feet. One inch on the chart equals 0.10 foot; one-tenth of an inch on the chart equals 0.01 foot stage height.

The present procedure at Hubbard Brook involves reading stage heights to the nearest .001 foot; the first two places as actual measurements, and the third place by interpolation. This means that one-tenth of an inch on the chart is further divided into 10 hypothetical subdivisions. As the pen trace on the streamflow chart varies from 0.001 to better than 0.002 inch wide, stage height reading to the nearest 0.001 foot is little more than a guess.

To check on the relative accuracy of reading stage heights to the nearest 0.001 versus 0.005 or 0.01, a year's streamflow record was tabulated. All stage heights for the dormant season (Oct. 16 - May 15) 1959 and the growing season (May 16 - October 15) 1960 from Watershed No. 3 were rounded off to the nearest 0.005 foot and 0.01 foot.

A comparison was also made between a four-place rating table that we now use and a three-place rating table. Lower flows showed a slight difference; higher flow, no difference; and average flows, no difference.

From this analysis, it appears that reading stage height to the nearest 0.005 foot and use of a three-place rating table would provide reasonably accurate data.

Table 3.--Streamflow recordings at Hubbard Brook

GROWING SEASON - 1960

Number of decimal places in stage height reading	May-June	June-July	July-Aug	Aug-Sept	Sept-Oct
	Area inches				
0.001	2.266	0.494	0.761	-0.181	0.208
.005	2.244	.494	.754	.182	.208
.01	2.265	.491	.761	.181	.209

DORMANT SEASON - 1959

Number of decimal places in stage height reading	Oct.-Nov.	Nov.-Dec.	Dec.-Jan.	Jan.-Feb.	Feb.-Mar.	Mar.-April	April-May
	Area inches						
0.001	10.016	8.333	2.489	1.825	1.032	10.839	7.069
.005	10.014	8.330	2.492	1.824	1.038	10.837	7.058
.01	10.011	8.332	2.438	1.818	1.048	10.860	7.078

SUMMARY TOTAL

Number of decimal places in stage height reading	Growing season	Dormant season	Annual
0.001	3.910	41.603	45.513
.005	3.882	41.588	45.470
.01	3.907	41.585	45.492

CHECKING STREAMFLOW DATA

Raymond E. Leonard

Checking streamflow data is an integral part of watershed management research. It has two primary functions--(1) to pick up errors in the original data and (2) to familiarize the researcher with current data.

For several years an intensive program of data checking was in operation at Hubbard Brook. Under this system each individual marking on the A-35 chart, tabulation, and computation was checked before filling the data.

Some results of this intensive checking procedure are as follows:

Watershed No. 3, Growing Season (May 16 - October 15) 1960.--A total of 566 breaks were marked on the hydrograph during the season. Eight errors in stage height were picked up during this period. Six of these were cases where the break was marked, but stage height was not noted on the chart. Two were mistakes in reading or balancing the stage height curve.

Ten errors in time were found either from the time being omitted or noted wrong on the streamflow chart. No errors were picked up on the Form 66 for this period.

Watershed No. 1, Growing Season (May 16 - October 15) 1960.--A total of 639 breaks were marked on the hydrograph during the season. Five errors in stage height were picked up during this period. Two of these were cases where the stage height break was marked but not noted on the chart. There were mistakes in reading or balancing the stage height curve

Four errors in time were found either from the time being omitted or noted wrong on the streamflow chart.

One discharge factor was incorrectly noted and one discharge factor was omitted from the Form 56A. No error was found in time or daily c.s.m. computations. No errors were picked up on the Form 66 for this period.

The net change in streamflow data resulting from this checking was a total of 135 cubic feet of water for Watershed No. 3. The average daily flow of water for this period was 8,862 cubic feet, or 1,347,024 cubic feet per growing season. An error of .0001 percent would have resulted had no checks been made.

L-66 11/55
RI-NE
Water Relations
Runoff

U. S. Department of Agriculture
Forest Service

DRAINAGE DISCHARGE DATA
Mean c.s.m. by Days, Months, and
Growing Season

Experimental area: ______ Computed by: ______
Drainage basin No. ______ Area: ______ acres Checked by: ______

Date	May-June	June-July	July-Aug.	Aug.-Sept.	Sept.-Oct.
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26					
27					
28					
29					
30					
31					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
Total					
Mean					
Area inches					
In.precipitation					
Runoff % of pre.					

	For 5 months ending Oct. 15	For 12 months ending Oct.15
Total	______	______
Mean	______	______
Area inches	______	______
In. precipitation	______	______
Runoff % of pre.	______	______

Period: May 16, 19___ to October 15, 19____

With approximately 550 breaks in the hydrograph during the growing season and an even larger number during the dormant season, it is quite doubtful if any error in reading or tabulating the data could be of great magnitude, relative to the rest of the data.

Tabulation of the data on Form 56a offers several possible cross-checks during the computation process. An error in reading the time will usually show up in Column (2) or Column (4). For example, a misreading of the 24-hour time shows up in Column (2) and thus prohibits time computations in Column (4). It is obvious that stage height or time omitted from the tabulation would prohibit computation of daily c.s.m. Column (6). A check on the upper dial of a desk calculator during the computation of daily c.s.m. will verify the 1440 minutes per day

Errors in the tabulation of gage height and rating factors on Form 56a, and computations of daily c.s.m.'s are not readily picked up except through an individual checking process

The intensity of data checking should depend largely on the experience of the personnel concerned. An experienced man marking streamflow charts does not require an intensive check of his data. We feel that when an experienced person does the original marking, a simple editing of the chart by a professional is sufficient. Spot checks are made at this time for errors in marking and correcting, and paying closer attention to periods of rapid change in stage height such as spring snow-melt runoff or summer storms. Final summary tabulation is also spot-checked. With our present procedure this takes less than 4 hours of professional time per water-year per station.

MORE ON CHART CORRECTIONS

George Hart

The purpose of this report is to evaluate our present methods of chart corrections and to determine the loss of accuracy which would occur if these corrections were discontinued. We now are making adjustments for three kinds of error: time, gage height, and chart expansion (errors in skew are very infrequent, small, and are handled like gage height errors). These corrections are time-consuming and, if they can be eliminated without greatly reducing the accuracy of measuring discharge, the work load will be substantially reduced.

Before getting into the chart correction problem, it will be necessary to think about what we want these data for.

The immediate need will probably be to calibrate the watersheds before treatment. On the Fernow watersheds, calibration data consisted of: (1) annual, seasonal, and monthly flow in area-inches; (2) peak flows which exceeded a certain discharge, and (3) number of days of low flows below a certain discharge.

In other studies, it is possible that individual storms or periods of runoff will be compared. Data will also be used to develop depletion curves and other interpretative information. Our hydrographs will probably be used for several kinds of studies, each perhaps requiring different accuracies.

METHODS

Accuracy gained by corrections was determined by retabulating elapsed times and gage heights without making corrections. The recomputed daily c.s.m. were compared with the daily c.s.m. with corrections. In some instances only the expansion correction was eliminated (termed e.c.e.), in others only the time correction was eliminated (termed t.c.e.), in some all corrections were eliminated (termed uncorrected). Two periods of time were considered: an entire water year and individual periods of runoff (mid-winter thaw, spring runoff, summer storms)

RESULTS:

ANNUAL AND MONTHLY FLOWS

Example 1

Annual flow of Watershed No 3, 1958-9

Corrected flow	23.148 inches
t.c.e	23.152
e.c.e	23.059
Uncorrected	23 060

Correcting the charts changed the measured annual discharge .09 inch (23.15 - 23.06) from an entirely uncorrected chart. April runoff accounted for .06 inch of this change in discharge. During the year 32 time corrections (23 of them 30 minutes or under, and none over 60 minutes) were made. Expansion corrections usually apply over a 2-week period, and 23 of them were made

Large percentage differences can occur in daily c s.m. between corrected and uncorrected charts. For example, on September 26, the uncorrected c.s.m was 29 percent greater than the corrected c.s.m.; on July 5, the uncorrected was 8 percent less than the corrected. These large percentage differences occur during periods of very low flow where a small absolute difference in c s m amounts to a relatively high percentage of the flow. Such errors in low flows may be important in low flow analysis. At both these periods of high percentage difference, a correction for gage height error was being applied.

On a monthly basis, uncorrected c s m was about 0 75 percent less than the corrected c.s m. For July, however, the difference amounted to 2.25 percent: July was a period having many gage height corrections with relatively low flow. The small percentage difference between corrected and uncorrected charts indicates that uncorrected charts would present no difficulty to total monthly flow analysis for almost all months.

Example 2

Annual flow of Watershed No. 1, 1955-6

Corrected flow	32.98
e.c e.	33.12

Differences in monthly discharge between corrected and uncorrected charts were larger than those in Example 1 above A difference of 4.2 percent was found for October-November runoff. The usual difference amounted to about 1.5 percent--sometimes plus, sometimes minus. For annual flow analysis the difference between corrected and partly corrected charts is very small; there is greater need for corrections if data are to be used on a monthly basis.

Example 3

Daily flow of Watershed No. 1, 1958-9

Corrected flow for 39 days	3.86 inches
e.c.e.	3.83 inches

Apparently for this year, expansion errors were few. Greatest percentage difference between charts with corrections and without expansion corrections was 1.8 percent; the normal difference was well under 1 percent for any day.

A second phase of this problem involves short periods of time--2 weeks or less--during which streamflow is high and the hydrograph shows large fluctuations in gage height.

Example 4

Winter Thaw

The winter thaw occurring December 24 to December 31, 1957 was examined on the Watershed No. 2 charts and a comparison of corrected and uncorrected charts was made. During this 8-day period, the expansion correction was .007, based at .347, and the maximum correction applied was .005. Time correction amounted to 25 minutes. Discharge differences for the period were:

	Corrected	Uncorrected	Percent
Average daily c.s.m.	7 9341	7.8669	99.15
Area inches	.295	.293	99.32

For the two days of highest flow, the average daily c.s.m.'s were:

2/26	18.655	19.573	104.92
12/27	21.961	20 576	93.69

There are relatively large differences between corrected and uncorrected discharges on these two days.

Spring Melt

A large proportion, about half, of the total annual flow occurs during the spring melt period in April. For this reason, a number of comparisons of corrected, partly corrected, and uncorrected values were made. The results of these comparisons are summarized below:

Example 5 (Watershed No. 1)

Date	Corrected (c.s.m.)	t.c.e. (c.s.m.)	Percent
4/4/58	6.337	6.422 (25)	101.34
4/5/58	10.591	10.691 (30)	100.94
4/13/58	3.491	3.635 (80)	104.12

Period examined was just before major runoff and gage heights are not particularly high. Parentheses after the t.c.e. discharge indicate minutes of correction for each day. Notice that the 80 minutes error of 4/13/58 made a substantial difference in discharge. Also note that eliminating time corrections increased the discharge: clocks usually run slow and time correction at midnight is made by advancing the midnight break on the chart. Since a greater part of the hydrograph is on a recession curve, the corrected time is at a lower gage height than the uncorrected time point.

Example 6 (Watershed No. 1)

Date	Corrected (c.s.m.)	t.c.e. (c.s.m.)		e.c.e. (c.s.m.)		Uncorrected (c.s.m.)	Percent
4/15/58	14.472	14.472	(0)	14.358	(.003)	14.358	99.21
4/16/58	22.886	22.951	(5)	22.800	(.004)	22.866	99.91
4/17/58	25.799	25.848	(10)	25.544	(.004)	25.590	99.79
4/18/58	20.938	19.963	(10)	20.736	(.003)	20.791	99.30
4/19/58	12.879	12.840	(15)	12.801	(.002)	12.769	99.15
4/20/58	8.167	8.138	(20)	8.118	(.001)	8.084	98.98
Average daily c.s.m. over period	17.524	17.368		17.393		17.410	99.35
Area inches over period	3.91	3.88		3.88		3.88	99.23

The time correction was 20 minutes in a week and expansion correction was .007, base of .369. No gage height corrections were necessary. Maximum corrections applied each day appear in parentheses in the t.c.e. and e.c.e. columns. These are not particularly large expansions. Notice that the percentage difference for any single day did not exceed 1 percent between corrected and uncorrected charts. The flow for the period differed by .03 area inches. One reason why the expansion corrections were not greater was that the starting gage height--or zero line for expansion corrections--was rather high, .369. This is normal for spring runoff.

Example 7

Another comparison of corrected and totally uncorrected charts was made for Watershed No. 2 during the period from 4/14/58 to 4/23/58. Time error for the period was 20 minutes, and expansion error was .004, base .350. Maximum expansion correction was .002. The percentage difference for each day was about 0.5 percent; one day the difference was 1.5 percent. Average daily c.s.m. for the period was 19.757 corrected, 19.654 uncorrected; area inches discharge for the period was 7.35 inches corrected, 7.31 inches uncorrected. Again, when time and expansion corrections are small, the effect of eliminating corrections is trivial.

Example 8

The effect of eliminating corrections for somewhat larger expansion corrections during spring runoff is seen in comparisons of charts from Watershed No. 3, 4/14/58 through 4/23/58--the same period as given in Example 7 above. In this case, expansion error was .006, base .469. Maximum correction applied was .005. There were no time or gage height errors. Compared daily discharges look like this:

Date	Corrected (c.s.m.)	e.c.e. (c.s.m.)	Percent
4/14/58	6.356	6.345 (.001)	99.83
4/15/58	15.481	15.470 (.003)	99.93
4/16/58	28.472	27.479 (.004)	96.51
4/17/58	36.986	36.666 (.005)	99.13
4/18/58	35.167	34.976 (.005)	99.46
4/19/58	26.499	26.178 (.003)	98.79
4/20/58	18.028	17.856 (.002)	99.46
4/21/58	19.612	19.586 (.003)	99.87
4/22/58	21.349	21.127 (.003)	98.96
4/23/58	19.239	19.074 (.003)	99.14
Average daily c.s.m.	22.719	22.476	98.93
Area inches over period	8.45	8.36	98.93

The greatest percentage difference for one day was 3.5 percent On two other days the percentage difference was slightly over 1 percent. For the 10-day period there is about 1 percent difference both in average daily c.s.m. and in area inches for the period By correcting the charts for expansion, .09 area inch was gained. Differences in discharge between watersheds Nos 2 and 3 over this period are readily apparent, whether or not corrections for expansion are made. Watershed No 2 discharge was 7.35 inches corrected, 7.31 inches uncorrected; Watershed No 3 discharge was 8.45 inches corrected, 8.36 inches uncorrected. If corrections are made, the difference between watersheds is 1.10 inches; if corrections are eliminated, the difference is 1.05 inches.

Example 9

Finally, a hypothetical chart was drawn of spring runoff and a 1-hour error in time was assumed. Corrected and uncorrected discharges for a week were compared The differences in daily c.s.m. were about 0.5 percent, although on one day the difference was 1 8 percent. On days having large time corrections at 40 and 50 minutes, percentage differences were well under 1 percent Time corrections up to an hour have little effect on discharge for periods of high, fluctuating flow, because adjustment of the midnight break results in only a small change in gage height.

Summer Storms

Summer flow usually is low and contributes relatively little to annual flow Yet sudden storms raise the hydrograph from the range of low flows, and expansion errors in this period could be important. Take, for example, the storm of 7/28/58 to 7/31/58 and Watershed No. 3 discharge:

Date	Corrected (c s.m.)	e.c.e (c.s.m.)	Percent
7/28/58	.073	.073	100.00
7/29/58	2.300	2 255	98 04
7/30/58	1.034	1.016	98 26
7/31/58	.282	.277	98 23

The expansion error was .010, base 067, and the maximum correction applied was .004. On this storm, water level rose from .067 to a peak of .507 Had it risen higher, the correction applied would have been greater Percentage difference between corrected and uncorrected discharge was about 2 percent. For the storm there is a difference of 02 c.s.m.

Expansion errors usually run .006 to .012; almost every chart has an expansion error, although sometimes the correction is not applied because the water level does not raise enough. Expansion corrections are not pro-rated over time; instead, they depend upon how much the water level rises or falls from the point at which the pen was set at the beginning of the 2-week chart. Hence expansion corrections can be compensating--they are not necessarily in the same direction over a period of time like gage height corrections are. Usually, however, the net effect of eliminating expansion corrections is to reduce gage heights and thus to reduce discharge. This happens because, with an expanded chart, the pen traverse at 10 inches falls inside the chart margin at reversals. To bring the hydrograph trace to the scale on the expanded chart it is necessary to add a correction of several thousandths in gage height.

By eliminating both time corrections and expansion corrections, one elimination can compensate partly for the other. For example, Watershed No. 3 April 1959 discharges are as follows:

	Corrected	t.c.e.	e.c.e.	Uncorrected
Average daily c.s.m.	11.5168	11.5194	11.4664	11.4672
Percent of corrected		100.02	99.56	99.57

With t.c.e. the average daily c.s.m. slightly exceeded the corrected values and e.c.e fell short of corrected values. The uncorrected value, 11.4672 c.s.m., was closer to the corrected value than was the e.c.e. value. This compensating effect does not always take place.

RECOMMENDATIONS

These recommendations are made in the belief that discharge data will be used primarily for watershed calibration in the form of annual flow, peak flows, number of low-flow days. Should the discharge data be used for other purposes, it may be necessary to go back to the charts and make corrections in certain periods of flow. For this reason, if corrections are not originally made, the amount of error should be indicated on the chart and a notation made that the chart is not corrected.

1. Continue to make all corrections for gage height and skew errors.

2. Eliminate all expansion corrections up to .007 (applied value).

3. Eliminate time corrections for periods when error is 60 minutes or less.

4. For maximum peaks, indicate both corrected and uncorrected for expansion value. Compute discharge on the uncorrected gage height if expansion correction as applied would be 007 or less

In addition to these changes, I would suggest that extra effort be put to the job of keeping clocks running within 15 minutes, or at the most, 30 minutes This means re-setting them each week if they are more than 15 minutes off and keeping several spare clocks in top-notch condition, ready to be immediately installed. Greater effort should be made to keep expansion error reduced--either by dessicant bags, or changing the tightness of linkage, or a combination of factors.

I suggest we change the midnight and noon lines from the heavy broken line to the heavy solid line. It is more logical to have the major time divisions represented by heaviest solid line.

I suggest we leave the chart on the recorder for longer periods of time. Reversals could be made; time and gage height adjustments made; notes regarding debris, ice, or miscellaneous could be written on the chart without cutting it off every two weeks. By changing charts each two weeks, the possibility for errors in unequal take-up (skew) are increased; more time is consumed changing charts; time is consumed glueing charts together again; and the general task of handling, rolling, and unrolling so many charts is annoying Why not let the charts run for several months if there is no appreciable change in the hydrograph--during the relatively uniform periods of mid-winter and summer flow? Should a unique storm or high-runoff period occur, then the charts could be immediately changed and that period of discharge studied I have also found that folded charts are cumbersome to work with and wonder if they could be filed in rolls rather than folders

NEW METHODS FOR MEASURING STREAMFLOW

R. S. Pierce

ANALOG-TO-DIGITAL RECORDER

Operation.--The major objections to the use of streamflow recorders that produce a trace chart is the time required to convert stage height to discharge and to tabulate and summarize the data suitable for computation. Further, there are well known inaccuracies in the use of these recorders both from features inherent in the instrument and from human inability to transcribe the data accurately.

One means of eliminating some of these difficulties is to convert the mechanical thrust imparted by the float to a punched digital binary decimal coded tape. Such a device is now available with a dry cell battery for a power source, thereby making it suitable for stations inaccessible to power lines. Stage height is punced on a continuous roll tape that can in turn be fed into a translator to convert the information to a punch card machine or read-out device and ultimately transcribed to discharge in tabular form.

A commercially available recorder that has the above features is manufactured by the Fisher and Porter Company of Warminster, Pa. It is called the Analog-to-Digital Recorder or ADR. This instrument may be operated on a 5 minute, 15 minute, or 1 hour read-out interval. Stage heights from .01 foot to 99 feet may be read; special gears and pulleys may be obtained so that readings to .001 foot are possible. Float arrangements similar to those used with the FW-1, A-35, or other chart recorders are also used for the ADR, i.e., a stilling well, float, tape, and pulley. Torque imparted by the moving float rotates two rib-coded wheels which in turn align a series of punches preparatory to punching the tape for the read-out. A battery (7.5 volt dry cell) operates a clock and the punching mechanism. On a 15-minute read-out a battery will last about 1 year and at a 5-minute read-out it will last about 6 months. The continuous roll tape will last for 1.5 years at a 15-minute read-out, and 6 months for a 5-minute interval.

There are 16 binary digits (4 groups of 4 numbers--1, 2, 4, and 8) enabling any combination of numbers to be punched. For example 56.13 would have the following digits punched: 1st group--1 and 4, 2nd group--2 and 4, 3rd group--1, and 4th group--1 and 2.

The ADR also can be equipped with an amplifier, servo motor, and potentiometer to transmit millivolt signals for telemetering.

Performance.--First models of the ADR had some "bugs", but apparently these have been corrected and later models are relatively trouble-free. The clock and timing mechanism is exceptionally accurate by normal streamgaging standards--an error of 5 minutes or less in a 6 month period is the rule. Errors in stage height are negligible with a maximum variance of .01 foot (for .01 foot smallest reading) and .002 foot (for .001 foot smallest reading). Oftentimes the error may occur because the instrument was set wrong initially.

Although the instrument appears complicated at first glance with an array of both mechanical and electrical parts, the recorder is simple in operation, and from past experience requires little to no maintenance, adjustment, or repair. Reports by Hibbert [5/] and Curtis [6/] describe their experiences with the ADR.

Cost.--The initial cost of the ADR is about $500. Instruments equipped with a .001 foot minimum reading cost slightly more. Tape costs $7.50 a roll.

Transcribing the data.--There are several methods for transcribing the data from the tape:

1. Ocular reading of the tape. With experience the tapes may be read directly, and their values either tabulated or plotted in analog form, if necessary. Such procedure would be applicable for close observation of the data, e.g. examining storm runoff periods or when the amount of record is not large.

2. Conversion to punch cards. Taped data may be transcribed to punch cards automatically and further converted to discharge by inserting the stage height discharge relationship into the computer.

The Geological Survey sends their ADR tapes to Washington for transcribing, and for $50/year/gaging station get discharge in tabular form for average, maximum, minimum, and total monthly and yearly data.

5/ Hibbert, A. R. Experience with the Fischer-Porter Analog-to-Digital recorder. Sept. 1961, 3 pp., mimeo. Southeastern Forest Expt. Sta., Coweeta Hydrologic Lab.

6/ Curtis, Willie R. The Fischer-Porter Analog-to-Digital Recorder--Report on Experience at La Crosse, Wisconsin, Oct. 1961, 5 pp., mimeo. Lake States Forest Expt. Sta.

Advantage.--Because the data are punched on a digital system, there are no errors in time or stage height stemming from paper expansion. The electric clock system keeps excellent time regardless of extreme ranges in temperature. The instrument seems to be relatively trouble free. The greatest advantage is the form in which the data are produced. It can be used in direct examination of streamflow, or automatically converted to discharge without human handling of the data, which oftentimes produces errors. Where a large amount of records are anticipated, and where summations of data such as average monthly or yearly flow are needed, this instrument is ideal.

Disadvantages.--Initial cost is slightly higher for the ADR ($500) than for conventional analog recorders such as the A-35 ($440) or the FW-1 ($260).

The major disadvantage is the inability to scan the record easily to observe streamflow fluctuations, such as is possible with chart recorders.

BUBBLE GAGE

Operation.--Conventional stream-gaging stations commonly have mechanical systems to convert stage height measurements to a graphical or binary log. Such systems usually employ the standard stilling well, float and tape. There are a number of disadvantages with this system: (1) The installation of a stilling well may not be possible at some otherwise suitable gaging site, (2) the construction of the well and associated intake-pipes may be costly at certain locations, (3) pipes may become clogged with debris with consequent record loss, and (4) in cold climates where wells are subject to freezing, additional features must be added to assure ice-free conditions.

A new instrument is available which does not require the well and float arrangement. This is called the Bubble Gage. Gas is released from an opening well below zero flow in the control section. As the pressure of the water above the opening increases or decreases with rising and falling stages, this pressure change is detected by a sensitive well of mercury, which can command a motor to rotate a pulley attached to a water stage recorder.

This instrument can be located at any convenient location regardless of direction, distance or height above the water surface. A single high pressure plastic tube, 3/8-inch in diameter, extends from the instrument to a metal orifice mounted on an immovable base below the water surface. The motor which turns the pulley on the water stage recorder is battery operated. A tank of nitrogen gas serves as a source of bubbles.

Cost.--The Bubble Gage may be purchased for about $680 from the U. S. Geological Survey. Leupold and Stevens have an almost identical model for $1,350. Two 7.5-volt batteries and a tank of gas will last about one year.

Performance.--The Geological Survey is installing Bubble Gages at all new locations, and will gradually introduce them at existing stations. In spite of the small opening through which the gas is released below the water, the Survey has had practically no problem with clogging.

The instrument is capable of detecting changes in stage height to as little as .001 foot. Although barometric pressure does affect the instrument, it is not believed to influence appreciably stage height measurements.

Ice on the water surface above the orifice should not influence the instrument any more than with ice above a conventional intake pipe. Wave action in the main channel would cause the instrument to seek continually the water surface, and cause undue battery drain if it were not for an electronic relay servo control that is attached. This control has a built-in-memory. It will activate the instrument only if there is a repeated higher or lower, as the case may be, stage height within a 30-second interval. Thus actual rising or falling stages would activate it, but quick surges or wave action would not.

Advantage.--The major advantage of this instrument is that it eliminates the need for a stilling well at a gaging station and the problems associated with stilling wells.

Disadvantages.--Cost and possible mechanical and electrical difficulties are the major drawbacks. As it is seemingly true with most instruments, the greater the complexity the greater the chance for breakdowns.

NEW METHODS FOR COMPILING STREAMFLOW DATA

Irvin C. Reigner

Although the machine methods of compilation described in the following presentation are new to us, the watershed management personnel of the Northeastern Forest Experiment Station, they are not exactly new. A year ago, Ron Hibbert wrote a paper describing the Oscar K which they put in operation sometime earlier. Clyde Shumway, on the San Dimas staff, recently wrote to me about the Gerber machines, which they have been operating over a year. Ron Hibbert is here with us and will give his opinions. Shumway says they are well satisfied with the Gerber.

Before we proceed further, let us discuss briefly an older machine that has been used to compile streamflow data. The streamflow integrator is a planimeter-type instrument that may be used to determine discharge directly in c.f.s. per day. The instrument rides along a track placed on the baseline of the chart; a pointer is used to follow the hydrograph trace.

The discharge integrator was developed by the U. S. Geological Survey, I believe, and was in use in some of their offices several years ago. Coweeta used it for some time. In a detailed analysis, made in 1960, they found that results were in error by 3 to 5 percent. On the other hand, the results of manual picking were very close to the standard they had developed. About this time the Oscar K was purchased and the integrator was abandoned.

Ken Reinhart, Dick Sartz, and Bob Pierce also investigated the use of the discharge integrator. Their main objection was its inability to measure flows under 0.2 foot head. As the flows at their weirs were under 0.2 foot a considerable part of the time, they were not enthusiastic about the integrator It has not and will not be considered any further.

Benson-Lehner, the manufacturer of the Oscar K, now makes a dual encoder machine, the Oscar F, which allows the simultaneous readout of the X and Y axes (time and head) This increases reading speed one-third and decreases the number of operator errors, as there is one less positioning of overlays for each point (two instead of three).

The Coweeta staff experienced a fair amount of trouble in the operation of the Oscar K. They finally nailed it down to a faulty connecting assembly between the Oscar K and the IBM card punch. In addition, they found more difficulty than expected in keeping the data free of errors; they are spending a good deal of time checking and rechecking data after they have been punched and again

after computing. So, the machine does not eliminate the error problem; while it may reduce the human errors, it introduces some mechanical errors.

Gerber Scientific Instrument Company produces machines with quite similar capabilities, limitations, and cost. Their GDDRS-3B-1 is a single encoder system like the Oscar K, while the GDDRS-3B-2 is the dual system. The people at the Gerber factory told me that practically every instrument they ever made is somewhat different from all other instruments. They are constantly adding improvements and adapting to the specific job.

Initial cost of the two machines is almost exactly the same. Gerber's dual encoder system lists for $6,975.00 including the keyboard, circuitry and cable connections for the outputs ordered, dust covers, and instruction manuals. I understand the first year of maintenance is also included at this price, but it does not include any output machines--electric typewriter, key punch, or tape punch. The single encoder system lists for exactly $2,000 less. Benson-Lehner's list prices for the Oscar models are exactly the same. As far as we know, these machines cannot be rented.

The IBM key punch, which is the most reasonable output machine for our use, can be rented for about $35.00 per month. Gerber lists the cost of an IBM output writer (an electric typewriter) at $950.00. Most likely this could also be rented.

Comparative data on these instruments are few. Shumway says the San Dimas operators read 5,000 points per year of record, on the average. This is very high and I suspect they use an arbitrary time interval rather than have the operator decide on the time interval. To read this number of points takes 17 to 18 working hours, or about 3.5 hours per 1,000 points. Ron Hibbert's report does not mention the number of points the Coweeta operators read on the Oscar K, but notes a reading time from 7 to 12 hours per year including some editing of charts and checking of punched cards. If the number of points they read on the Oscar K is similar to the number they require for hand-picking (1,600 to 2,000), about 4.5 to 6 hours are needed to read 1,000 points. As the latter is a single-encoder system, the longer time per thousand points is reasonable.

By now, the advantages and disadvantages are fairly obvious. Here, however, is a consolidated listing as I see them:

ADVANTAGES

1. These machines are unquestionably faster than hand point-picking--probably 3 to 4 times faster per unit number of points.

2. Accuracy is probably greater. Presumably, the machine will make fewer errors reading time and head than will a human being.

3. The data on punched cards are in more useful form for subsequent computation than data written on a sheet of paper, and are ready for machine tabulation and machine processing. The Coweeta people have a program for a Honeywell 800 computer. If we had our data on cards, they could be processed by our computer service unit at Yale.

DISADVANTAGES

1. The initial cost may be a problem to the underfinanced Watershed Management Division budget.

2. Efficient machine operation requires two operators, whereas hand picking can be done efficiently by one person.

3. Probably more points would be read by the machine than would be needed by hand point-picking. Many days require only one head reading by hand methods, but the machine requires a reading at the end of each day. This would not be the average head for the day.

4. Data on a punch card are not easily readable. The computer can tabulate the readings in the next step, if it is desired. Or a tabulation of data may be typed right from the reader, using an electric typewriter on the output circuit.

SUMMARY OF DISCUSSION

DESIGN OF WATERSHED STUDIES

The lack of replication in watershed studies was pointed out (Bickford) though replication in time was conceded (Satterlund). With no replication in space, results must be assigned only to the experimental watershed, making each a case history (Bickford). Perhaps the concept of utilizing a statistical distribution is unworkable in research that involves experimental watersheds. Are there then any other approaches that would work such as non-parameter calculations? (Bickford).

Considerable variation in results from like-treated watersheds at Coweeta suggest need for more basic studies (Hibbert).

A watershed study, like any other, requires a clearcut, specific objective--a star to steer by--and this objective calls for a specific analysis (Bickford).

STANDARDS OF ACCURACY

We need to develop standards of accuracy for all elements of data analysis (Reinhart). Measurement errors should be defined such as errors caused by debris and also errors that result from office work (calculator errors, for instance). From a study of these errors, the allowable error can be set: the minimum error that can be tolerated in relation to design (Bickford). What sizes of differences are important? Within the context of the particular problem what size of difference has meaning, that is, can be considered real, or have practical importance? This difference is not necessarily the same as a statistically significant difference which in a poorly designed experiment may either be much longer or much smaller (Wilson). We have found 0.06 inch significant in monthly streamflow and consider 10 percent of annual streamflow of statistical importance (Reinhart). Coweeta feels that a 1-inch difference would be significant (Hibbert).

DATA CHECKING AND CORRECTIONS

Daily discharges for a series of watersheds can be checked by plotting and overlaying to correct the oddballs (Hibbert). In the Forest Survey, field data are checked by a sampling procedure, also the computer can be used for checking (Bickford). Checking may be particularly needed during periods of low flow (Reinhart). The kind of checks mentioned here can all be done by computers (Wilson). Checking necessary to keep compilers on toes (Reinhart). If time of storm peaks is needed, time errors should be corrected; otherwise, no need to make corrections (Leonard). At Coweeta no correction is

made for time errors of 1 hour or less (Hibbert).

STREAMFLOW MEASUREMENT

Accuracy of Pygmy meter questioned as a means of calibrating weirs; Coweeta has used volumetric methods to calibrate all weirs but Cipolletti's (Hibbert).

The gas bubbler has a device for damping the recording of surges and wave action; apparently bed load and debris do not create problems.

A heating device to keep stilling-well free of ice was described (Pierce). Rock salt suggested as a means of clearing ice from weir pond (Hibbert).

The Fischer-Porter ADR at Hubbard Brook has performed very satisfactorily; no time error in 3 months; very accurate water height record (Pierce). A 15-minute readout would probably give instantaneous peaks as accurately as chart recording devices; 105,000 5-minute readouts per year can be reduced to 400 or 500 cards per year; if we get the money Coweeta will go over to these machines (Hibbert).

ELECTRONIC COMPUTERS (WILSON)

EDP (electronic data processing) machines can do anything with data that a man can do unaided or with other pieces of data processing equipment. Furthermore, the job can be done at less cost generally, always with greater accuracy and with much greater speed. The best way to test the truth of this statement is to try it.

Data records can be sorted and counted. Particular records can be selected from a group of records. Records can be checked for errors, and the errors can be corrected or the record rejected. Any mathematical or logical operation can be performed on the data.

The machines perform these functions by a series of simple arithmetical and logical (choosing or branching) steps. The choice of steps and their proper sequencing is controlled by an internally stored program or list of instructions to the machine.

Preparation of this program can be the log jam in the use of electronic computers. Fortunately, programs are already written and available for wide range of common computing problems. However, processing jobs that are unique require a specially prepared program. This may be expensive and time-consuming to produce if the problem is complex. Processing of streamflow data, however, will require only a simple and inexpensive program.

Programming begins with a flow chart that fully describes the data processing problem. The data which are to be processed must be fully described, even to the number of digits and the position of the decimals. The flow chart must show how each piece of datum is to be used to arrive at the data to be gotten out of the processing; and this output, too, must be exactly described. This information must be supplied to the programmer by the person who has the data processing problem.

In jobs consisting of simple operations on large quantities of data, the bottleneck may be in punching the data rather than in programming. The data source for any electronic computer must be cards or paper tape in which the data is represented by punched holes, although at some intermediate stage the data may be represented in some other way like magnetized spots on magnetic tape. This disadvantage could easily be overcome with streamflow records by using an instrument like the Fischer-Porter ADR in their collection.

Because there are many ways of processing streamflow records, the best mix of men and machines to use seems to be a subject that is worthy of some actual research.

PRESENT PROCEDURES FOR RECORDING, COMPILING, AND CHECKING

Kenneth G. Reinhart

Procedures at Laconia, New Lisbon, and the Fernow are generally similar and satisfactory. The job of recording is pretty well under control. Some difficulties have been met but methods of taking care of them have been developed. There are a few differences in methods of compiling. Perhaps the major one is the use of clerical personnel at the Fernow.

Considerable difference of opinion was expressed as to the need for checking. Suggestions ranged from complete checking at each step (except those that are self checking) to spot checking or screening for major errors to no checking at all.

The same was true of the need for corrections. It appears that omitting corrections for time results in negligible error. Errors in stage have more effect but rarely enough to make a lot of difference. Corrections for paper expansion are being made on the A-35 charts only; these are the most time-consuming but do not usually amount to as much as those for skew or unexplained errors.

Questions were raised as to the basis for the table governing permitted rise before making a break in the hydrograph, and whether or not this table should be revised.

Charts are now being read (or attempted) to 0.001 foot. It is generally recognized that this is perhaps unrealistic and that negligible differences would occur if reading was extended to a larger amount. Both 0.005 and 0.01 were mentioned.

The need for a mensuration study was discussed. In particular this would be concerned with the setting of an accuracy objective and the determination of the kind and magnitude of error associated with each step in the measurement process.

Various figures were presented for the time involved in the compiling job. General averages for a water year as given were: New Lisbon, 26 hours; Fernow, 38 hours; and Hubbard Brook, 52 hours. On the Fernow there were about 1,000 intervals per year; for the New Lisbon data, about 865. One reason for the higher figure in man hours at Hubbard Brook might be the fact that all charts involved were for the A-35. At the Fernow the A-35 charts took longer. Cost for one water year of record on the Fernow, including 10 percent added for odds and ends, was about $88. This might be taken as a general average though the stop-watch technique is somewhat unrealistic. Perhaps a better figure would be about $100 per station year of record.

Recommendations

1. The current methods be continued, for the present at least, in more or less the manner in use.

2. Consideration be given to changing the reading of stages from 0.001 to 0.005, or possibly to 0.01. Effect on daily values should be considered in this review.

3. Consideration be given to liberalizing (rather than omitting) the making of corrections for time and stage. Perhaps time corrections need be made only if time is off by one hour or more. Corrections for expansion might be ommitted.

4. The need for checking should be reviewed. Perhaps a system of spot checking and scanning for major errors can be devised. The comparison of plotted data holds promise, particularly since the plotted data may have other uses.

5. A mensuration study should be made, the main question being its scope and intensity. Determination of an objective in accuracy, perhaps varying by discharge classes, should be made, and an estimate of accuracy attained by present methods arrived at by study of errors associated with successive steps.

6. Looking toward possible direct punching of gage height, a study should be made at each location of the differences in daily and other discharges that would have resulted if no corrections had been made for debris or other "unauthorized" rises in the hydrograph. In this connection, methods of minimizing the debris problem (such as removing trees or other debris sources near the weirs and improvement of equipment or procedures for keeping debris out of the notches) should be investigated.

The current method of operation is a pretty good one. It does not appear that the automatic methods can do the job much better or cheaper if we are satisfied with mean daily flow as the basic building block. Other methods might give us much more detail: a study of possible analysis methods to make good use of this greater detail should be undertaken and fairly specific plans made for such analysis before we undertake compilation in a more detailed manner.

COMPARISON OF VARIOUS MACHINE METHODS OF RECORDING AND COMPILING STREAMFLOW DATA

Irvin C. Reigner

Although it is difficult to compare each of these procedures accurately, it is possible to put the results of each procedure on a fairly comparable basis: the production of a set of IBM cards with all of the time-head points punched on it. If we continue our present procedure, we may not want IBM cards for further calculation but they can be used, and the results are comparable.

Considering, first, the Fischer-Porter Analog-to-Digital recorder, the main obstacle is the initial cost. To equip all of our streamgaging stations with ADR's would require an outlay of about $15,000 at an average list price of $500 per recorder. There are 27 stations (9 at Fernow, 6 at Hubbard Brook, 3 each at Newark and Baltimore, and 6 at Penn State); three stations are flume-weir combinations requiring an extra recorder for each. Thus, a total of 30 recorders would be needed. If 30 recorders could be purchased in one or two lots, the price probably would be reduced to, say, $450 per unit, or $13,500 in total.

The ADR's record directly on paper tape, which must be translated to cards by a Fischer-Porter translator. The only estimate of translating cost was $120 per year (Hibbert says Fischer-Porter quoted a price of $10 per station-month) which seems high.

At a 5-minute punch out, 18 cards per day, or 6,520 cards per year (at a cost of $6.52) would be required for each recorder. On a 15-minute punch out basis, only one-third as many cards would be required for purchase, punching, and storage--a much more reasonable amount.

If the initial cost ($13,500) were amortized over a 10-year period, with a fairly reasonable price of $25 per water year for translating, the total cost to the Division would be $2,100 per year ($1,350 + $750). According to all who have experience with the ADR, accuracy would be extremely high.

The cost of the chart reader on an annual basis would be: $700 for initial cost, $540 for the rental of a printing key punch (12 x $45), and $1,320 for operator's time (30 x 22 hours x $200), or a total of $2,560. About 1,500 points would be read, requiring about 128 cards, a far cry from the number needed for the ADR. Accuracy would be good, but not as high as the ADR.

Our present procedure, the manual point-picking method, requires no additional outlay for equipment. It is a reliable

procedure that has worked satisfactorily; greater efficiency can undoubtedly be effected by standardizing the details of the procedure and by deleting such refinements as point-by point checking and reading to the nearest thousandth of a foot. Greater efficiency could also be obtained if the compilation were done on an annual or periodic basis rather than weekly.

The best estimate of the time required to tabulate all points for 1 year is 11.5 hours for 3 station years of Baltimore watershed stations. The average number of points was 865, a rather low figure reflecting the relatively even flow of the watersheds.

A moderate estimate of the annual cost of chart tabulation (all time-head points on a standard form) would be 30 stations x 15 hours x $2.00 or a total of $900. A high estimate would be 30 stations x 20 hours x $2.50 or a total of $1,500.

The cost of having these data punched on IBM cards should not run over $10 per station year. The number of time-head points should average about 1,500, requiring 128 cards per water year. Estimating the cost of about $300 for all card punching, the total cost of manual tabulation would be $1,200 to $1,800. Accuracy would be only fair, the lowest of the three methods, but still probably greater than the accuracy of the weir producing the original records.

To summarize, the ADR's would provide the most accurate tabulation of streamflow, with the least manpower necessary, for a cost of about $2,100 per year. No chart would be available for editing or correcting.

The chart reader would provide a somewhat less accurate tabulation for about $2,560. Charts would be available for editing and correcting errors, before tabulation.

A high estimate of the cost of continuing our present manual method is $1,800 per year. The least accurate tabulation would be produced, but probably it would be still more accurate than the weirs or the recording instruments. Charts would be available for editing, correcting, and future study.

The recommendations are fairly obvious:

1. As there is no present backlog of untabulated charts, nor any promise of a backlog, the chart reader is not justified.

2. There would be no significant saving, in dollars or manpower, by converting to ADR's.

3. Although an extremely accurate tabulation is provided by the ADR, if there are no debris or freezing problems, and if the recorder is set accurately, there is no easy way to correct the record if these contingencies do occur. As they may be corrected rather readily if the recorder chart is available, the ADR should probably not be used where inexperienced observers service the instruments or where debris and freezing problems cannot be prevented.

4. There seems to be no advantage of the A-35 over the FW-1, as all stations are visited weekly. But there are several disadvantages: chart expansion and contraction, and a longer tabulating time. Therefore, if FW-1 recorders become available on surplus, they should replace the A-35's.

WHAT TO DO

Howard W. Lull

Our review of present methods of collecting and compiling streamflow data leads to three conclusions:

1. With present methods, streamflow compilations of daily discharge have been kept up to date. We have no backlog.

2. The compilation methods are simple and relatively inexpensive. It costs in the neighborhood of about $100 to compile a water-year record. Machine methods will cost less (perhaps around $60 a year) but no major saving can be anticipated.

3. Compilation procedures used at the three projects are quite similar There are minor differences in respect to methods of chart correction and checking that can be worked out.

Our review of machine methods suggests:

1. A chart scanner would be useful if we had a large backlog of records or if it offered the best method of compiling future records. However, we don't have such a backlog and it doesn't offer the best method

2. The Fischer-Porter ADR instrument has the advantage of accurate collection of data in a form adaptable to machine analysis. We will save little money by using this instrument but it offers distinct possibilities of doing a better job

What then should we do? To begin with, we are not going to switch to ADR's next week: we don't have the money And if we had it I'm not certain that all projects would want to change. The stage of present studies and the wishes of our cooperators must be considered. So our present methods, I expect, will be continued for some time. Pertaining to these methods, I would like to make three assignments:

1 That Reinhart dig out the explanation for the point-picking system that all Projects are using, review it for adequacy, and send his comments and recommendations to the other Projects and Upper Darby

2. That within 30 days of receiving these Proceedings each Project should review their compilation methods in respect to material presented herein, make necessary revisions as to methods of chart correction, checking, and decimal carrying-out. These revisions should be incorporated into your present procedural handbooks, and you should notify other Projects and Upper Darby as to your decisions.

3. That Hornbeck should bring together all material as to errors in streamflow measurement and data compilation and prepare by January 1 a paper on this for publication.

Finally, as to purchase of ADR's, we can approve their purchase only if it can be justified. Apparently, it cannot be justified on a money-saving basis but it may be on the basis of making it possible for a more intensive utilization and analysis of data. To get these instruments, you will have to think this through and convince us that with them you can get results not now possible with our present procedures.

APPENDIX:

I

OUTLINE OF STREAMFLOW DATA COMPILATION AT THE COWEETA HYDRAULIC LABORATORY

Alden R. Hibbert

I. Coweeta Streamflow Records - Processing History

A. Manual methods to 1952.

B. Discharge integrator 1952-1960 (this also caught up the back work.)

1. No point values - (daily, monthly, seasonal and annual totals of streamflow.)

2. Accuracy fair for month or longer periods - daily values as much as 5 percent off during storm periods.

C. Semiautomatic chart reader beginning in 1961.

1. Began by putting 1-year data on cards by manual point picking:

a. Intervals 1/2 to 2 hours.
b. Head to closest thousandth of foot.

2. Experimentation showed that:

a. Time intervals should vary from 5 minutes to 24 hours.
b. Manual head reading to nearest .003 foot is about all that can be expected. (To the nearest .005 foot is good enough as long as no bias involved.)

3. Oscar-K chart reader.

a. Convert analog trace to digital values on cards.
b. Mechanics of reading a chart trace.

II. Data Processing Procedure, Output, and Costs

A. Data processing procedure.

1. Editing of original recorder charts (time, head corrections, etc.).

2. Reading with Oscar-K (automatic card punching).

3. Installation of sequence numbers in cards.

4. Computer check (checks card data for sequence of time readouts, magnitude of head values, blank or double punched columns, number of days in month, months in year, etc.).

5. Correction of errors found by 4.

6. Computer rechecks 4 of years corrected.

7. Computation of card data.

   a. Time-head conversion to time c.s.m. units and total discharge for day, month, 3-month, 6-month, 9-month and 12-month periods in c.s.m. and area inches-tabulated--6 months to a sheet.

   b. Flow frequencies for 3, 6, 9, and 12-month periods-semi-logarithmic flow class interval breakdown--actual time units and percent of time in each class interval tabulated.

   c. New set of data cards with time-c.s.m. units.

8. Check and correction of computations (7). Involves manual checking against old forms--new data against control watershed.

9. Precipitation and other information is added to complete tabulations (new Form 7's).

B. Costs of data processing.

		Per Water Year
1.	Purchase price Oscar-K - $5,000 (assume about 7 years to depreciate).	$ 4.30
2.	Service Contract $700 (to be increased next year to $1,050).	4.30
3.	Rental IBM 024 Card Punch - $35 per month.	2.50
4.	Twelve hours for reading each water year (average of GS-5 and GS-1 or $2.00 per hour).	24.00
5.	Four hours for manual checking and correction for each water year at $2.00 per hour.	8.00
6.	Sequence numbers, computer checks and computation and tabulation (this cost figure has included programming in the past; it should decrease).	15.00
7.	Cards and miscellaneous items.	.90
	Total	$59.00

8. Above does not include overhead or other incidental costs such as filing cabinets, handling, and storage costs, breakdown time, etc.

C. Problems with checking and correction.

1. Bigger job than anticipated (the job decreased considerably as operator learned what to be careful about).

2. Types of errors most common:

   a. Misreading the trace (some probably machine).
   b. Time sequence (operator and machine).
   c. Wrong number of days in month (operator).
   d. Improperly applying trace correction (operator).
   e. Not enough points (operator), (infrequent).

III. Status of Data Processing

A. So far, 209 years through computing step. About as much more to go, which will take another year. (Two to 3 months per year to keep abreast, after caught up.)

B. Other types of records may be processed.

C. Card data experience:

1. Original intent was for machine analysis.

2. Have found that quality of data has been considerably improved (double checking as well as better work have resulted). Discharge integrator was off especially for short periods of time.

3. Flow frequencies are available for first time--may open way for new methods of analysing low flows and changes in timing of yield; now working on this.

D. Biometrics will aid us in finding or fitting flow distribution curves with mathematical model.

E. A mathematical definition of base flow recession through a storm period should enable programming of computer to separate storm runoff and open way for computer analysis of storm flows without manual separation techniques.

II

MAXIMUM PERMISSIBLE RISE IN STAGE BEFORE BREAKING CURVE IN POINT-PICKING METHOD

K. G. Reinhart

In the point-picking method of determining quantity of discharge from the hydrograph, it is necessary to place some limitation on the change in stage allowed in each interval for which discharge is computed. Table 4 is the table in use on the Fernow Experimental Forest; all gaging stations on this Forest are 120° v-notch weirs.

This table was apparently developed jointly by the Elkins Unit and personnel of the U. S. Geological Survey. It appears that the object was to determine allowable rises, at various stages, that would result in maximum errors of no more than 2 percent stemming from the fact that mean stage does not correspond exactly to the average discharge of the interval. This Appendix attempts to evaluate the adequacy of the table.

Some salient features of this Table of Permitted Rise are shown in table 5. In this table:

Col. 1 is merely an identification number.

Col. 2 gives the lower limit, designated H_1, of selected stage classes.

Col. 3 gives the upper limit, H_3, of the stage classes.

Col. 4 shows the permitted increase in stage for the class (from table 4).

Col. 5 gives the value for H_2 (this is H_1 plus the increase permitted for the stage class).

Col. 6 gives the ratio of H_2 to H_1.

Col. 7 gives the permitted increase in stage expressed as a percentage of H_1.

Col. 8 gives, for selected items, the error in cubic feet per second of a discharge determination having the given permissible rise. How this error was determined will be shown below.

Col. 9 gives the same error expressed as a percentage of the true value.

Col. 10 gives the number of intervals used in determining the true value.

Henry Anderson of the Pacific Southwest Forest and Range Experiment Station furnished us with a copy of his "Notes on Discharge Calculations for v-notch Weirs" dated May 4, 1959 with "Supplements" dated August 4, 1959. For a weir with formula almost identical to ours, he gives a table for determining error in percent for different values of the ratio H_2/H_1. In our table 5, the values for H_2/H_1 are all 1.3. Interpolating in Anderson's table, a ratio of 1.3 corresponds to an error of 1.0 percent.

In table 5, permitted increases were between 27 and 33 percent of H_1. Our approach is conservative in respect to Anderson's recommendation that "the hydrograph should be broken at 50 percent changes in stage, whether the trace continues straight or not."

In order to get a better understanding of the errors involved, some additional comparisons were made. For items 2, 4, 7, and 10 an attempt was made to determine the true discharges.

True discharge was computed by separating the interval into a number of segments each with mean stage of 0.001 foot more than the previous one. (For item 10, segments differed by 0.005 foot because that is the way our discharge table is made up.) Discharge in c.f.s. for the period is determined by averaging the discharge of these many intervals; the number of intervals is shown in Column 10 of table 5. This should be a close approximation to the true discharge. Discharge is also computed by determining mid-stage and referring to the same discharge table. Comparison of the two is made to determine the error. The computations are illustrated in table 6.

In each case the error comes out to a little less than one percent, an acceptable error in respect to streamflow differences judged to be significant.

Determining the error involved when using permitted rise is only a part of the story. In working up our data on the Fernow, how does the actual amount of rise before breaking stage compare with the permitted rise? To answer this, the record for one year (1959-60) on one Watershed No. 4 was studied.

The actual rises used (table 7) are generally considerably less than the permitted rises. The arithmetic mean of the actual rise (col. 6) is shown as a percentage of the permitted rise (col. 8). These range from 9 to 100 percent. The percentages are generally smaller in the higher stage classes. The simple arithmetic mean

of the percentages for all 25 stage classes is 42 percent.

The arithmetic mean leaves something to be desired when there is a great variation in the duration of intervals. For instance, for a given head an error of 0.5 percent for a 5-minute interval is a lot different than the same percentage error over a 24-hour interval. Therefore, the mean actual rise was computed weighting each value for the duration of the interval (col. 7). The table also shows this weighted mean as a percentage of the permissible rise (col. 9). The mean percentage for all classes, again weighted for duration of interval, is 39 percent.

It is easy to see why the actual rise averages less than the permitted rise. We always break at midnight and, for many days, the change in flow is less than the permitted rise. Also, we often break on the even hour or at a point of irregularity in the trace even though the permitted rise has not been reached.

In summary, our permitted rise table seems adequate from the standpoint of estimating the errors involved or by reference to Anderson's recommendations. A further safety factor is added by the fact that the actual rises we are using are on the average only about 40 percent of the permitted rises.

And finally, it became apparent during this review of procedures that the magnitude of any error is dependent not only on the amount of rise involved but also upon the duration of the interval. With the Fernow hydrographs there were many instances where permissible rises were exceeded within intervals of less than 5 minutes. Interval breaks of this order are difficult to make and are of minor consequence. I recommend that a minimum interval length of 20 minutes be used regardless of the amount of rise involved.

Table 4.--Maximum rise of water (head) before breaking curve
(Data read from curve)
For 120° v-notch

Head	Permitted increase in head	Head	Permitted increase in head
.000 - .030	0.005	1.001 - 1.050	0.280
.031 - .060	.010	1.051 - 1.100	.290
.061 - .100	.020	1.101 - 1.150	.310
.101 - .150	.030	1.151 - 1.200	.320
.151 - .200	.040	1.201 - 1.250	.340
.201 - .250	.060	1.251 - 1.300	.360
.251 - .300	.070	1.301 - 1.350	.370
.301 - .350	.080	1.351 - 1.400	.380
.351 - .400	.100	1.401 - 1.450	.400
.401 - .450	.110	1.451 - 1.500	.420
.451 - .500	.120	1.501 - 1.550	.430
.501 - .550	.140	1.551 - 1.600	.450
.551 - .600	.150	1.601 - 1.650	.460
.601 - .650	.170	1.651 - 1.700	.470
.651 - .700	.180	1.701 - 1.750	.490
.701 - .750	.200	1.751 - 1.800	.510
.751 - .800	.210	1.801 - 1.850	.520
.801 - .850	.230	1.851 - 1.900	.540
.851 - .900	.240	1.901 - 1.950	.550
.901 - .950	.250	1.951 - 2.000	.570
.951 -1.000	.270		

Table 5.--Maximum rise and its significance

Item No.	Head H_1	Head H_3	Perm. in-crease	$H_2 = H_1 +$ in-crease	H_2/H_1	Perm. incr. as per-cent of H_1	Error c.f.s.	Error Per-cent	No. inter-vals
	Feet		Feet	Feet		Percent	c.f.s.	Per-cent	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	.000	.030	.005	.005	--	--	--	--	--
2	.031	.060	.01	.04	1.3	33	-.00001	0.8	10
3	.061	.100	.02	.08	1.3	33	--	--	--
4	.101	.150	.03	.13	1.3	30	-.0002	0.9	30
5	.151	.200	.04	.19	1.3	27	--	--	--
6	.401	.450	.11	.51	1.3	27	-.0057	0.9	111
7	.651	.700	.18	.83	1.3	28	--	--	--
8	.901	.950	.25	1.15	1.3	28	--	--	--
9	1.151	1.200	.32	1.47	1.3	28	--	--	--
10	1.401	1.450	.40	1.80	1.3	29	-0.13	0.9	81
11	1.951	2.000	.57	2.52	1.3	29	--	--	--

Table 6.--Computation of error for item 2 in table 5

1. For class 0.031 to 0.060 foot, permitted increase is 0.010 foot.

2. For convenience in computation, consider the discharge of a straight hydrograph segment starting at 0.0305 foot and ending at 0.0405 foot.

3. Divide into 10 equal segments, list mid-stage of each segment, and add and divide to determine mean discharge for interval, as follows:

Mid-stage of segments	Discharge in c.f.s.
.031	.0009
.032	.0009
.033	.0010
.034	.0011
.035	.0012
.036	.0013
.037	.0014
.038	.0015
.039	.0016
.040	.0017
Sum	.0126
n	10
Mean	.00126

Mean stage

$$\frac{0.0305 + 0.0405}{2} = .0355 \text{ foot}$$

Discharge for mean stage
(Interpolating between 0.035 and 0.036 foot) = 0.00125 c.f.s.

"Error"
0.00126 - 0.00125 = 0.00001 c.f.s.

Percent "Error"
100 (0.00001/0.00126) = 0.8%

Table 7.--Relation of actual rise to permitted rise, Fernow Watershed 4, 1959-60 water year

Stage Class			Number of intervals	Permitted rise	Actual rise		As percent of permitted rise	
Item No.	H_1	H_3			Arith. mean	Weighted mean	Arith. mean	Weighted mean
	Feet	Feet		Feet	Feet	Feet	Percent	Percent
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	.000	.030	198	.005	.003	.001	60	20
2	.031	.060	111	.010	.010	.009	100	90
3	.061	.100	96	.020	.015	.012	75	60
4	.010	.150	96	.030	.020	.017	67	57
5	.151	.200	89	.040	.022	.015	55	38
6	.201	.250	119	.060	.018	.014	30	23
7	.251	.300	93	.070	.023	.019	33	27
8	.301	.350	49	.080	.036	.035	45	44
9	.351	.400	55	.100	.039	.038	39	38
10	.401	.450	25	.110	.058	.070	53	64
11	.451	.500	22	.120	.047	.048	39	40
12	.501	.550	17	.140	.064	.075	46	54
13	.551	.600	10	.150	.083	.106	55	71
14	.601	.650	6	.170	.058	.058	34	34
15	.651	.700	7	.180	.102	.100	57	56
16	.701	.750	8	.200	.077	.084	39	42
17	.751	.800	8	.210	.087	.082	41	39
18	.801	.850	3	.230	.071	.102	31	44
19	.851	.900	2	.240	.090	.090	38	38
20	.901	.950	1	.250	.076	.076	30	30
21	.951	1.000	3	.270	.084	.082	31	30
22	1.001	1.050	1	.280	.050	.050	18	18
23	1.051	1.100	4	.290	.027	.031	9	11
24	1.101	1.150	5	.310	.041	.033	13	11
25	1.151	1.200	2	.320	.061	.061	19	19